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CONTENTS.

The Logical Basis of the Sanitary Policy of Mosquito Reduction: SIR RONALD ROSS.... 689

Scientific Books:—
Poynting and Thomson's Heat: PROFESSOR J. S. AMES. *Freeman on Minnesota Plant Diseases:* PROFESSOR CHARLES E. BESSEY. *Mayer on Sea-shore Life:* PROFESSOR T. H. MORGAN 699

Societies and Academies:—
The American Mathematical Society: PROFESSOR F. N. COLE. *Northeastern Section of the American Chemical Society:* DR. A. M. COMEY. *The Chemical Society of Washington:* DR. A. SEIDELL. *The Philosophical Society of Washington:* CHARLES K. WEAD. 701

Discussion and Correspondence:—
Dr. O. F. Cook's 'Social Organization and Breeding Habits of the Cotton-protecting Kelep of Guatemala': DR. WILLIAM MORTON WHEELER. *Isolation and the Origin of Species:* PROFESSOR F. E. LLOYD. *The Small Mounds of the United States:* DR. D. I. BUSHNELL, JR.... 706

Special Articles:—
The Loch Leven Trout in California: PRESIDENT DAVID STARR JORDAN. *The Relation of Soil Texture to Apple Production:* HENRY J. WILDER. *A Correction of the Generic Name (Dinochœrus) given to Certain Fossil Remains from the Loup Fork Miocene of Nebraska:* O. A. PETERSON.... 714

Quotations:—
Academic Freedom in Japan.... 719

Notes on Entomology: DR. NATHAN BANKS.. 720

Botanical Notes:—
Index of North American Fungi; The Fern Allies of North America; The Grasses of Iowa; Experiments with Plants: PROFESSOR CHARLES E. BESSEY.... 721

International Exploration of the North Sea. 723

Greek at Cambridge.... 724

The American Psychological Association.... 724

Scientific Notes and News.... 725

University and Educational News.... 727

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THE LOGICAL BASIS OF THE SANITARY POLICY OF MOSQUITO REDUCTION.[1]

THE great science of preventive medicine is often called upon to consider new policies of public sanitation, which, whether they ultimately prove successful or not, are always of profound interest and importance to mankind. Quite recently a new measure of this kind has been proposed, which in the opinion of many promises to rank with house sanitation and preventive inoculation as a means of saving human life on a large scale. Unfortunately, its value has not yet been clearly demonstrated—with the result that it is not being employed as largely as some of us hoped would be the case. I feel, therefore, that I can not better acknowledge the honor you have done me in inviting me to address you to-day than by attempting to discuss this important theme—in the hope that the discussion may prove profitable to the cause of public health. The new sanitary policy to which I refer is that which aims at the reduction of disease-bearing insects, especially those which are the disseminating agents of malaria, yellow fever and filariasis.

I presume that it is scarcely necessary to discuss the evidence which has established the connection between various insects and arthropods and many diseases of man and of animals. The fact that the pathogenetic parasites which produce those great scourges of the tropics just mentioned are carried by gnats is now too well known to require reiteration. It is necessary only to

[1] Read at the International Congress of Arts and Science.

remind you that the gnat acts as an intermediary, becoming infected when biting infected persons and, some weeks later, infecting healthy persons in its turn—the parasite passing alternately from insect to man. The hypothesis that the infection in these diseases may be produced in any other manner than by the bite of gnats has not been justified by any recorded experiments or by any substantial arguments; and we may, therefore, assume for the present that if we could exterminate the intermediary agents, the gnats, in a locality, we could also exterminate there the diseases referred to. But here we enter upon ground which in the opinion of many is much less secure. While some believe in the possibility of reducing gnats in given localities and consider that the point has been proved by experiment, others are much more sceptical and hold that the experiments were not sound. This state of uncertainty naturally causes much hesitation in the adoption of measures against gnats, and, therefore, possibly a continued loss of life by the diseases occasioned by them; and I, therefore, propose to sift the matter as carefully as time will allow.

In the first place, we should note that experiments made in this connection have not been very satisfactory, owing to the fact that no accurate method has yet been found for estimating the number of gnats in any locality. We can express our personal impressions as to their numbers being small or large; but I am aware of no criterion by which we can express those numbers in actual figures. We can not anywhere state the exact number of mosquitoes to the square mile or yard, and we can not, therefore, accurately gauge any local decrease which may have resulted from operations against them. A method of doing this may be invented in the future; but for the present we must employ another means for resolving the problem—one which has given such great results in physics—namely, strict logical deduction from ascertained premises.

As another preliminary we should note that mosquito-reduction is only part of a larger subject, namely, that of the local reduction of any living organisms. Unlike particles of matter (so far as we know them) the living unit can not progress through space and time for more than a limited distance. The diffusion of living units must, therefore, be circumscribed—a number of them liberated at a given point will never be able to pass beyond a certain distance from that point; and the laws governing this diffusion must be the same for all organisms. The motile animal is capable of propelling itself for a time in any direction; but even the immotile plant calls in the agency of the winds and waters for the dissemination of its seeds. The extent of this migration, whether of the motile or the immotile organism, must to a large degree be capable of determination by proper analysis; and the logical position of the question of local reduction depends upon this analysis.

The life of gnats, like that of other animals, is governed by fixed laws. Propagation can never exceed, nor mortality fall below, certain rates. Local conditions may be favorable either to the birth rate or to the death rate; and the local population must depend upon the food supply. Diseases, predatory animals, unfavorable conditions and accidents depress the density of population; and in fact local reduction, that is, artificial depression of the density of population, practically resolves itself into (*a*) direct destruction and (*b*) artificial creation of unfavorable conditions.

Let us now endeavor to obtain a perfectly clear picture of the problem before us by imagining an ideal case. Suppose that we have to deal with a country of indefinite extent, every point of which is

equally favorable to the propagation of gnats (or of any other animal); and suppose that every point of it is equally attractive to them as regards food supply; and that there is nothing, such for instance as steady winds or local enemies, which tends to drive them into certain parts of the country. Then the density of the gnat population will be uniform all over the country. Of course, such a state of things does not actually exist in nature; but we shall nevertheless find it useful to consider it as if it does exist, and shall afterwards easily determine the variations from this ideal condition due to definite causes. Let us next select a circumscribed area within this country, and suppose that operations against the insects are undertaken inside it, but not outside it. The question before us is the following: How far will these operations affect the mosquito density within the area and immediately around it?

Now the operations may belong to two categories—those aimed at killing the insects within the area, and those aimed at checking their propagation. The first can never be completely successful; it is in fact impossible to kill every adult winged gnat within any area. But it is generally possible to destroy at least a large proportion of their *larvæ,* which, it is scarcely necessary to remind you, must live for at least a week in suitable waters, and which may easily be killed by larvacides, or by emptying out the waters, or by other means. This method of checking propagation consists, in the case of these insects, of draining away, filling up, poisoning or emptying out the waters in which they breed. Obviously the ultimate effect is the same if we drain away a breeding pool or if we persistently destroy the larvæ found in it; though in the first case the work is more or less permanent, and in the second demands constant repetition. If we drain a breeding area we tend to produce the same effect at the end of a year as if we had destroyed as many gnats as otherwise that area would have produced during that period. Thus, though we can not kill all mosquitoes within an area, even during a short period, we can always arrest their propagation there for as long as we please, provided that we can obliterate all their breed waters or persistently destroy all their larvæ—which we may assume can generally be done for an adequate expenditure. We must, therefore, ask what will be the exact effect of completely arresting propagation within a given area under the assumed conditions?

The first obvious point is that the operation must result in a decrease of mosquitoes. If we kill a single gnat there must be one gnat in the world less than before. If we kill a thousand every day there must be so many thousands less at the end of a given period; and the arrest of propagation over any area, however small, must be equivalent to the destruction of a certain number of the insects. But this does not help us much. It may be suggested that, after the arrest of propagation over even a considerable area, the diminution of mosquitoes within the area remains inappreciable. What is the law governing the percentage of diminution in the mosquito density due to arrest of propagation within an area?

The number of gnats (or any animal) within an area must always be a function of four variables, the birth rate and death rate within the area, and the immigration and emigration into and out of it. If we could surround the area by an immense mosquito bar, the insects within it (after the death of old immigrants) would consist entirely of native insects; on the other hand, if we arrest propagation, the gnat population must hereafter consist entirely of immigrants. The question, therefore,

resolves itself into this one: What is—what must be—the ratio of immigrants to natives within any area? What factors determine that ratio?

Ceteris paribus, one factor must be the size of the area. If the area be a small one, say of ten yards radius, suppression of propagation will do little good, because the proportion of mosquitoes bred there will be very small (under our assumed conditions) compared with those which are bred in the large surrounding tracts of country, and which will have no difficulty in traversing so small a distance as ten yards. But if we completely suppress propagation over an area of ten miles radius, the case must be very different—every gnat reaching the center must now traverse ten miles to do so. And if we increase the radius of the no-propagation area still further, we must finally arrive at a state of affairs when no mosquitoes at all can reach the center, and when, therefore, that center must be absolutely free from them. In other words, we can reduce the mosquito density at any point by arresting propagation over a sufficient radius around that point.

But we now enter upon more difficult ground. How large must that radius be in order to render the center entirely mosquito-free? Still further, what will be the proportion of mosquito reduction depending upon a given radius of anti-propagation operations? What will be that proportion, either at the center of operations, or at any point within or without the circumference of operations? The answer depends upon the distance which a mosquito can traverse, not during a single flight, but during its whole life; and also upon certain laws of probability, which must govern its wanderings to and fro upon the face of the earth. Let me endeavor to indicate how this problem, which is essentially a mathematical one of considerable interest, can be solved.

Suppose that a mosquito is born at a given point, and that during its life it wanders about, to and fro, to left or to right, where it wills, in search of food or of mating, over a country which is uniformly attractive and favorable to it. After a time it will die. What are the probabilities that its dead body will be found at a given distance from its birthplace? That is really the problem which governs the whole of this great subject of the prophylaxis of malaria. It is a problem which applies to any living unit. We may word it otherwise, thus—suppose a box containing a million gnats were to be opened in the center of a large plain, and that the insects were allowed to wander freely in all directions—how many of them would be found after death at a given distance from the place where the box was opened? Or we may suppose without modifying the nature of the problem that the insects emanate, not from a box, but from a single breeding pool.

Now what would happen is as follows: We may divide the career of each insect into an arbitrary number of successive periods or stages, say of one minute's duration each. During the first minute most of the insects would fly towards every point of the compass. At the end of the minute a few might fly straight on and a few straight back, while the rest would travel at various angles to the right or left. At the end of the second minute the same thing would occur—most would change their course and a very few might wander straight on (provided that no special attraction exists for them). So also at the end of each stage—the same laws of chance would govern their movements. At last, after their death, it would be found that an extremely small proportion of the insects have moved continuously in one direction, and that the vast majority of them

have wandered more or less backward and forward and have died in the vicinity of

Distance from center	nl	$(n-1)l$	$(n-2)l$	$(n-3)l$	etc.	total.
Number of gnats	$2\ +$	$4n$	$+\ 2\dfrac{2n(2n-1)}{2\,!}$	$+\ 2\dfrac{2n(2n-1)(2n-2)}{3\,!}$	$+$ etc. $=$	2^{2n}.

the box or pool from which they originally came.

The full mathematical analysis determining the question is of some complexity; and I can not here deal with it in its entirety. But if we consider the lateral movements as tending to neutralize themselves, the problem becomes a simple one, well known in the calculus of probabilities and affording a rough approximation to the truth. If we suppose that the whole average life of the insect contains n stages, and that each insect can traverse an average distance l during one such stage or element of time, then the extreme average distance to which any insect can wander during the whole of its life must be nl. I call this the limit of migration and denote it by L, as it becomes an important constant in the investigation. It will then be found that the numbers of insects which have succeeded in reaching the distances nl, $(n-1)l$, $(n-2)l$, etc., from the center will vary as twice the number of permutations of $2n$ things taken successively, none, one, two, three at a time, and so on—that is to say, as the successive coefficients of the expansion of 2^{2n} by the binomial theorem. Suppose, for convenience, that the whole number of gnats escaping from the box is 2^{2n}—a number which can be made as large as we please by taking n large enough and l small enough—then the probabilities are that the number of them which succeed in reaching the limit of migration is only 2; the number of those which succeed in reaching a distance one stage short of this, namely, $(n-1)l$, is $2.2n$ of those which reach a stage one shorter still is

$$2\frac{2n(2n-1)}{2\,!}$$

and so on. Hence the whole number of gnats will be found arranged as follows:

It, therefore, follows from the known values of the binomial coefficients that if we divide the whole number of gnats into groups according to the distance at which their bodies are found from the box, the probabilities are that the largest group will be found at the first stage, that is, close to the box, and that the successive groups, as we proceed further and further from the box, will become smaller and smaller, until only a very few occur at the extreme distance, the possible limit of migration. And the same reasoning will apply to a breeding pool or vessel of water. That is, the insects coming from such a source will tend to remain in its immediate vicinity, provided that the whole surrounding area is uniformly attractive to them.

The following diagram will, I hope, make the reasoning quite clear.

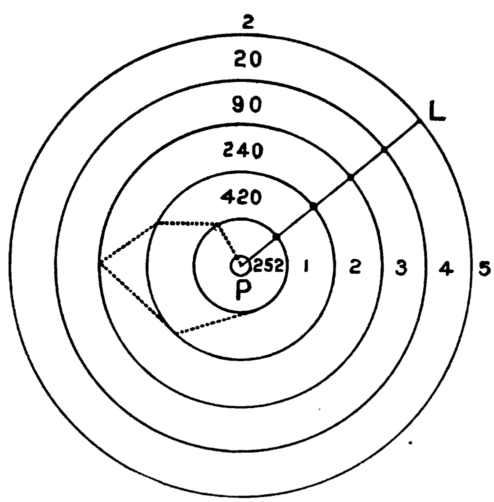

DIAGRAM I. The chance-distribution of Mosquitoes. P, central breeding-pool. L, limit of migration. The numbers denote the proportions of 1,024 mosquitoes starting from P which die at the distances 1, 2, 3, 4, 5, respectively. The continuous line denotes a continuous migration always in one direction; the dotted line, the usual erratic course.

We suppose that 1,024 mosquitoes have escaped during a given period from the central breeding-pool P, and we divide their subsequent life into 5 stages—the numbers 1,024 and 5 being selected merely for illustration. Rings are drawn around the central pool in order to mark the distance to which the insects may possibly wander up to the end of each stage; and the continuous line shows the course followed by one which has wandered straight onward all its life and has died at the extreme limit to which an insect of its species can generally go, namely, the outermost circle, L. On the other hand, the dotted line shows a course which is likely to be followed by the largest number of the 1,024 insects liberated from the pool—that is to say, a quite irregular to-and-fro course, generally terminating somewhere near the point of origin. The numbers placed on each ring show the number of mosquitoes calculated from the binomial coefficients when $n = 5$, which are likely to reach as far as that ring at the time of their death. Thus only 2 out of the 1,024 mosquitoes are ever likely to reach the extreme limit; while, on the other hand, no less than 912, or 89 per cent., are likely to die somewhere within the second ring around the center.

The same reasoning will apply whatever may be the number of mosquitoes liberated from the pool, or the number of stages into which we arbitrarily divide their subsequent life. Suppose, for example, that 1,048,576 mosquitoes escape from the pool and that we divide their life into 10 stages. Then only two of all these insects are ever likely to reach the extreme limit of the outermost circle; only 40 will die at the next circle; only 190 at the next; and so on—the large majority perishing within the circles comparatively close to the point of origin.

This fact should be clearly grasped. The law here enunciated may, perhaps, be called *the centripetal law of random wandering*. It ordains that when living units wander from a given point *guided only by chance* they will always tend to revert to that point. The principle which governs their to-and-fro movements is that which governs the drawing of black and red cards from a shuffled pack. The chances against our drawing all the twenty-six black cards from such a pack without a single red card amongst them are enormous; as are the chances against a mosquito, guided only by chance, always wandering on in one direction. On the other hand, just as we shall generally draw black and red cards alternately from the pack, or nearly so, so will the random movements of the living unit tend to be alternately backward and forward—tend, in fact, to keep it near the spot whence it started. As there is no particular reason why it should move in one direction more than another, it will generally end by remaining near where it was.

But it will now be objected that the movements of mosquitoes are not guided only by chance, but by the search for food. To study this point, take the diagram just given, place a number of pencil dots upon it at random, and suppose that each pencil dot denotes a place where the insects can obtain food—suppose, for example, that the breeding pool lies in the center of a large city and that the pencil dots are houses around it. Consideration will show that the centripetal law must still hold good, because there is no reason why the insects should attack one house more than another. There is no reason why a mosquito which has flown straight from the pool to the nearest house should next fly to another house in a straight line away from the pool, rather than back again, or to the right or left. The same law of chance will continue to exert the same in-

fluence, and the insects will always tend to persecute most those houses which lie in the immediate vicinity of their breeding pool. Even when there are many pools scattered about among the houses, there is no reason why, after feeding, the mosquitoes will go to one rather than to another; and the result must be that in general they will tend to remain where they were.

Self-evident as this argument may now appear, it is not understood by many who write on the subject and who seem to think that mosquitoes radiate from a center and shoot forever onward into all parts of the country as rays of light do. Accepting this fallacy without question, they argue that it is useless to drain local breeding pools because of the influx of mosquitoes from without. Such an influx certainly always exists; but I shall now endeavor to show that it can not generally compensate for local destruction.

Let us consider a tract of country over which numbers of mosquito-breeding pools are scattered, with houses and other feeding places lying among them. Suppose we draw a straight line across this country and drain away all the pools to the right of it, leaving all those to the left of it intact. Then all the insects on the left of the line must be natives of that part; and all those on the right of it must be immigrants which have crossed over the line from the left. How many mosquitoes will there now be on the right side, compared with those on the left side? The following diagram will enable us to consider this question more conveniently.

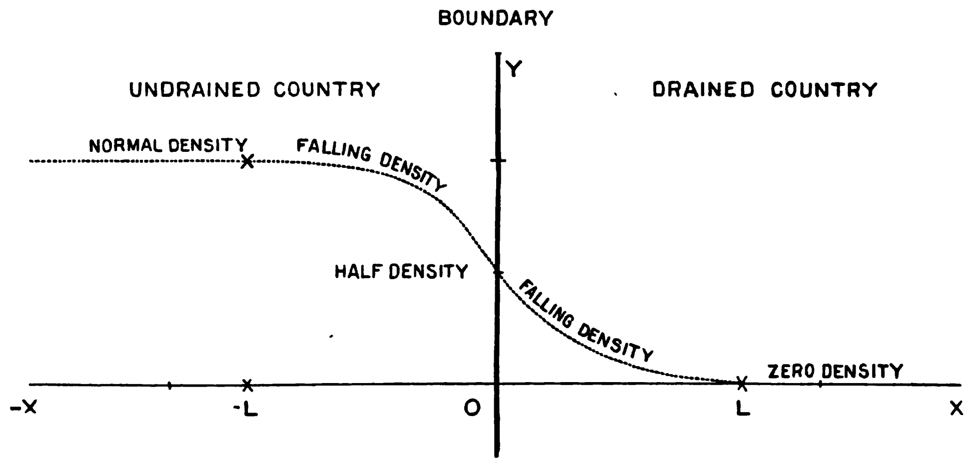

DIAGRAM II. Curve of falling mosquito-density due to drainage on right of boundary. L and $-L$ are the limit of migration on either side of the boundary.

First, examine the state of affairs before the drainage was effected. We may suppose that mosquitoes were then breeding fairly uniformly over the whole country, and that their density was much the same on both sides of the line. A certain amount of migration across the line, both from right to left and from left to right, must always have been going on; and since the density was equal on both sides, this migration must also have been *equal and opposite*—that is, as many emigrants must have been constantly passing from right to left as from left to right. Now, after the drainage has been effected, the following changes occur. The insects breed as before on the left of the line, and some con-

tinue as before to cross over it into the drained country; but, in the latter, on the right of the line, propagation is entirely checked and, moreover, the migration from it to the left of the line, which used to exist, now ceases. Hence not only must there be a decrease of mosquito-density on the right of the line, due to the local cessation of breeding, but also a decrease on the left of the line, due to the cessation of the migration from the right which formerly took place—that is to say, the drainage has affected the mosquito-density not only up to the line of demarcation, but beyond it. And moreover, since the migration was formerly equal from both sides of the line, it follows that now, after the drainage, the loss on the left side of the line due to the cessation of immigration from the right is exactly equal to the gain on the right due to the continuance of the immigration from the left. That is to say, the mosquitoes gained by immigration into the drained country must be exactly lost by the undrained country. This fact can be seen to be obviously true if we imagine an immense mosquito bar put up along the line of demarcation so as to check all migration across it, when, of course, the mosquito-density would remain as at first on the left, and would become absolute zero on the right: then on removing the mosquito-bar an overflow would commence from left to right, which would increase the density on the right by exactly as much as it would reduce the density on the left.

The dotted line on the diagram indicates the effect on the mosquito-density which must be produced by the drainage. If L is the possible limit of migration of mosquitoes (it may be one mile or a hundred, for all we know), the effect of the drainage will first begin to be felt at that distance to the left of the boundary line. From this point the density will begin to fall gradually until the boundary is reached, when it must be *exactly one half the original density*. This follows because of the equivalence of the emigration and immigration on the two sides. Next, as we proceed from the boundary into the drained country, the density continues to fall, until at a distance L on the right of the line, it becomes zero, the country now becoming entirely free of mosquitoes because they can no longer penetrate so far from the undrained country.

In the diagram the line giving the mosquito-density falls very slowly at first, and then, near the boundary, very rapidly, subsequently sinking slowly to zero. The mathematical analysis on which this curve is based is too complex to be given here; but it is not difficult to see that the centripetal law of random migration must determine some such curvature. The mosquitoes which are bred in the pools lying along the boundary line must remain for the most part in its proximity, only a few finding their way further into the drained country, and only a very few reaching, or nearly reaching, the limit of migration. Though an infinitesimal proportion of them may wander as far as ten, twenty or more miles into the drained country (and we do not know exactly how far they may not occasionally wander) the vast bulk of the immigrants must remain comparatively close to the boundary. And as, for the reason just given, the mosquito-density on the boundary itself must always be only one half the original density, it follows that it must become very rapidly still less, the further we proceed into the drained country. In fact, the analysis shows that the total number of emigrants must be insignificant when compared with the number of insects which remain behind—that is, when they are not drawn particularly in one direction. We are, therefore, justified

in concluding that, as a general rule, the number of immigrants into any area of operations must, for practical purposes, be very small or inappreciable a short distance within the boundary line. The following diagram probably represents with accuracy the effects of thorough suppression of propagation within a circular area.

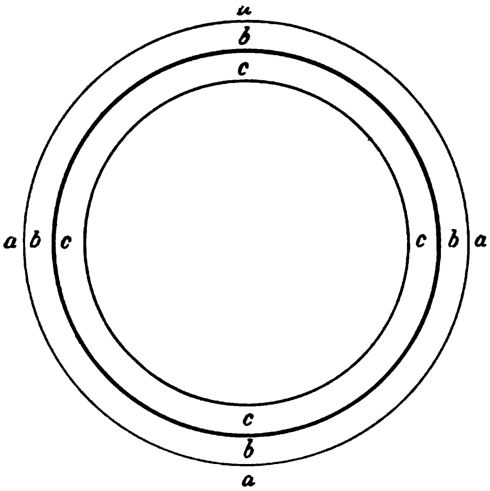

DIAGRAM III. Effect of drainage of a circular area. b = boundary of drained area. Mosquito-density begins to diminish at the circle a; becomes one half at the boundary b; and is small, inappreciable or zero at the circle c.

At the circle (a) and beyond it the mosquito density will be the normal density which existed before the operations were commenced. At (b), the circle bounding the drainage operations, the density will always be about half the normal density. At the circle (c) and within it, the density will be small, inappreciable or zero. The distance from (a) to (b) may be taken as being the same as that from (b) to (c); and, as the mosquitoes penetrating from (b) to (c) must be drawn from the zone between (a) and (b), the *average* result will be the same as if no immigration at all takes place. We do not possess sufficient data to enable us to calculate the actual distance between (a), (b) and (c)—this will depend in a certain measure on the activity of the species of insect concerned and on the existence or absence of special local attractions; but this fact does not discredit the general principles involved.

One case has not yet been considered, namely, that in which there exists only a single feeding place in the whole tract of country—such, for instance, as a single house or group of houses situated in the midst of deserted swamps. In such a case the insects may be compelled to come from considerable distances—from as far as their senses are capable of guiding them—in search of food; and drainage operations carried on with a view to relieving such a house may, for all we know, have to be extended over miles. But such cases are not of great consequence, because drainage is seldom the appropriate measure for isolated dwellings, which can generally be protected at far less cost by means of gauze screens. Moreover, it is very doubtful whether feeding places for mosquitoes are ever so solitary as the case assumes. Where there is one dwelling there are generally many, scattered at various distances over the country; and the insects are known to feed on cattle, birds and other animals. For towns, where anti-mosquito measures are most demanded, our first assumed condition of uniform attractiveness must, as a rule, be the one in force; and in such cases the centripetal law will hold.

The effect of wind required examination. Theoretically, if the insects are supposed always to remain on the wing, wind blowing on a generating pool will merely have the effect of drifting the whole brood to a certain extent in one direction without changing the *relative* positions of the insects to each other. The result would be the same as indicated in Diagram I., except that the generating pool would now be eccentric. If a proportion of the insects

take shelter, the circles of Diagram I. would become ellipses with the generating pool as a focus. In such a case the wind, and especially devious winds, would have a distributive tendency; but it must be remembered that if the insects are scattered further apart their members at a given point must be reduced. A wind which blows mosquitoes into an area must blow others out of it. The net result of devious winds on a circular drained area would be that the mosquito-density is not so much reduced at the center, but is reduced to a greater distance outside the boundary circle —so that the average reduction remains the same. With a wind blowing continuously from one direction, the indication would be to extend the drainage further in that direction. Obviously, wind may scatter mosquitoes; but it can not create them, nor prevent the total average reduction due to anti-propagation measures, as some people seem to think. It is, however, very doubtful whether wind does not really drive or scatter mosquitoes to any great degree. In my experience they are extremely tenacious of locality. Thus *Anopheles* were seldom seen on Tower Hill, a low open hill in the middle of Freetown, Sierra Leone, although numerous generating pools existed a few hundred yards from the top, all around the foot of it, and the winds were often very strong. If a continuous wind can drive mosquitoes before it, then during the southwest monsoon in India they should be driven away from the west coast and massed towards the east coast; but I have never heard that they are at all less numerous on the west coast. I have often seen very numerous mosquitoes on bare coasts exposed to strong sea-breezes, as at Madras. As a rule, they seem to take shelter in the presence of a strong breeze. Instances of their being driven far by winds are frequently quoted, but in my opinion they were more probably bred, in many such cases, in unobserved pools close at hand. The wind-hypothesis is frequently used by municipal officials as an excuse for doing nothing—it is convenient to blame a marsh miles distant for propagating the mosquitoes which are really produced by faulty sanitation in the town itself.

Another and similar statement is often made with all gravity to the effect that mosquitoes are brought into towns in trains, carts and cabs. So they are; but a moment's reflection will assure us that the number introduced in this manner must always be infinitesimal compared with those that fly in or which are bred in the town itself. Moreover, if vehicles may bring them in they may also take them out.

I will now endeavor to sum up the arguments which I have laid before you—I fear very cursorily and inadequately. First I suggested that there must be for every living unit a certain distance which that unit may possibly cover if it continues to move all its life, with such capacity for movement as nature has given it, always in the same direction. I called this distance the limit of migration. It should, perhaps, be called the ideal limit of migration, because scarcely one in many billions of living units is ever likely to reach it—not because the units do not possess the capacity for covering the distance, but because the laws of chance ordain that they shall scarcely ever continue to move always in the same direction. Next I endeavored to show that, owing to the constant changes of direction which must take place in all random migration, the large majority of units must tend to remain in or near the neighborhood where they were born. Thus, though they may really possess the power to wander much further away, right up to the ideal limit, yet actually they always find themselves confined by the impalpable but no

less impassable walls of chance within a much more circumscribed area, which we may call the practical limit of migration—that is, a limit beyond which any given percentage of units which we like to select do not generally pass. Lastly I tried to apply this reasoning to the important particular case of the immigration of mosquitoes into an area in which their propagation has been arrested by drainage and other suitable means. My conclusions are:

1. The mosquito-density will always be reduced, not only within the area of operations, but to a distance equal to the ideal limit of migration beyond it.

2. On the boundary of operations the mosquito-density should always be reduced to about one half the normal density.

3. The curve of density will rise rapidly outside the boundary and will fall rapidly inside it.

4. As immigration into an area of operations must always be at the expense of the mosquito population immediately outside it, the average density of the whole area affected by the operations must be the same as if no immigration at all has taken place.

5. As a general rule for practical purposes, if the area of operations be of any considerable size, immigration will not very materially affect the result.

In conclusion, it must be repeated that the whole subject of mosquito-reduction can not be scientifically examined without mathematical analysis. The subject is really a part of the mathematical theory of migration—a theory which, so far as I know, has not yet been discussed. It is not possible to make satisfactory experiments on the influx, efflux and varying density of mosquitoes without such an analysis—and one, I may add, far more minute than has been attempted here. The subject has suffered much at the hands of those who have attempted ill-devised experiments without adequate preliminary consideration, and whose opinions or results have seriously impeded the obviously useful and practical sanitary policy referred to. The statement, so frequently made, that local anti-propagation measures must always be useless, owing to immigration from outside, is equivalent to saying that the population of the United States would remain the same, even if the birth rate were to be reduced to zero. In a recent experiment at Mian Mir in India the astounding result was obtained that the mosquito-density was, if anything, increased by the anti-propagation measures—which is equivalent to saying that the population of the United States would be increased by the abolition of the birth rate. It is to be hoped that if such experiments are to be repeated they will be conducted by observers who have considered the subject. In the meantime, I for one must continue to believe the somewhat self-evident theory that anti-propagation measures must always reduce the mosquito density—even if the results at Havana, Ismailia, Klang, Port Swettenham and other places are not accepted as irrefragable experimental proof of it.

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SCIENTIFIC BOOKS.

A Text-Book of Physics: Heat. By J. H. Poynting and J. J. Thomson. London, Charles Griffin & Co. 1904. Pp. xvi + 354.

This text-book is the third of a series on general physics by the two distinguished scholars of Birmingham University and of Cambridge. The other two volumes are 'Properties of Matter,' which has already reached a second edition, and 'Sound,' the third edition of which has recently appeared. Two more volumes, on 'Light' and 'On Magnetism and Electricity,' are in preparation. As Professor Poynting says in the preface to

the volume before us, 'The text-book is intended chiefly for the use of students who lay most stress on the study of the experimental part of physics, and who have not yet reached the stage at which the reading of advanced treatises on special subjects is desirable.' With this end in view special attention is given the description of the fundamental experiments and special emphasis is laid upon the various assumptions, and the conditions under which the different theories hold.

It is of interest to note the order of arrangement of the matter in a text-book written by men so well known as teachers as well as investigators. There are in all twenty chapters, and their contents may be outlined as follows: Discussion of temperature; expansion with rise of temperature; quantity of heat, conductivity; conservation of energy; the kinetic theory of matter; change of state; radiation and absorption; thermodynamics, radiation.

A better order for the presentation of the subject of heat could hardly be imagined; and as one reads the chapters it is only at rare intervals that one feels called upon to offer any criticisms or to make any comments which are not most favorable. It may not be amiss to mention as being worthy of special praise the treatment of such subjects as the kinetic theory of matter, radiation, the porous plug experiment, the discussion of various phenomena in meteorology, the spheroidal state, and the theory of the radiometer. The most valuable feature of the book is undoubtedly the exact statement of the various theories and their limitations. Thus, in speaking of the radiometer, the authors say: "The theory is altogether beyond our scope, but the following account of what occurs may give some idea of the action. It is to be remembered that it is an account and not an explanation." Various sentences like this may be found throughout the book, and any student must be impressed with the great care taken to give a true account of both experiments and theory. There is one criticism, rather general in its nature, which may be passed upon the whole book, and that is that too much attention is given experiments and observations of former days at the expense of more modern work. It does not seem altogether advisable to discuss so fully experiments which were incomplete or mathematical laws which have been shown to represent the truth imperfectly. This is specially marked in the chapter on radiation. Again, in the description of certain forms of instruments, care is not taken to explain certain essential features in their accurate use, as, for instance, the Bunsen ice calorimeter. It would have been well, further, in discussing the difficulties of calorimetry to say a few words concerning the instrument perfected by Waterman. In the chapters dealing with the specific heat of water and the mechanical equivalent of heat good, bad and indifferent experiments are all described together, and a student is not told which are the best. If so many experiments and observations are to be described, it certainly would be best for a student to be told which are designed with the greatest care and which are the most trustworthy.

These slight criticisms are not meant in any way to reflect upon the excellent character of the book. As a text-book it stands by itself and should be put in the hands of every student of physics early in his course.

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Minnesota Plant Diseases. By E. M. FREEMAN, Ph.D., Assistant Professor of Botany, University of Minnesota. Report of the Survey, Botanical Series, V. St. Paul, Minnesota, July 31, 1905. Pp. xxii + 432. 8vo.

From time to time, it has been the pleasant task of the writer to notice the publication of the Botanical Survey of Minnesota, and to comment upon the thoroughly satisfactory style of publication adopted by the director, Professor Conway Macmillan, of the University of Minnesota. The volume now before us fully maintains the high standard set by the previous publications in this series. In its paper, type, illustrations and binding, this volume leaves nothing to be desired. As one turns over the pages, he is struck by the uniformly high quality of the illustrations, whether they are cuts from line drawings, or half-tones from photographs. They are all